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NOTES ON PYTHIUM ROOT ROT
VI

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Several experiments, in continuation of those cited in "Notes on *Pythium* Root Rot, V"* are discussed in this paper. To recapitulate, root rot of the sensitive Lahaina variety was greatly increased by amending "healthy" soil with stable manure and molashcake. An experiment was mentioned wherein an unsuccessful attempt was made to induce root rot of H 109 by the use of amendments of cane compost. H 109 and Lahaina, as well, grew luxuriantly without root rot in compost alone; Lahaina developed serious root rot, however, in half-and-half mixtures of soil and compost while H 109 had a healthy root system in this as in all mixtures from 20 to 90 per cent compost by volume. It was also mentioned that molashcake amendments greatly aggrava'ed *Pythium* root rot of Lahaina in "sick" Waipio soil, and induced serious root rot of Lahaina in healthy Makiki soil.

It was inferred that Lahaina roots rotted conspicuously when growth was stimulated by amendments of certain materials. H 109 differed from Lahaina in that growth could be greatly stimulated without the occurrence of *Pythium* root rot. The investigation of this point was carried to an extreme in Experiment 112, discussed below, wherein H 109 was grown in pots with soil amended with stable manure.

Experiment No. 112—Effect of Stable Manure on H 109

Sixteen 12-inch pots were prepared with pathology plot soil and stable manure amendments in various amounts by volume as shown in Table I. Cuttings of H 109 were planted November 24, 1928. On February 26, 1929, observations were made and the roots of one plant of each series were washed for examination.

TABLE I

Pot No.	Amendment	Root Rot Feb. 26th (Age 3 Months)	Root Rot May 28th (Age 6 Months)
1-4	Controls	None	None
5-8	25 per cent manure	Moderate	None
9-12	50 per cent manure	Serious	Slight
13-16	75 per cent manure	Serious	Moderate

Appearance of Plants: Control plants were rather pale and restricted in growth, apparently needing more plant food than the unfertilized soil supplied. The plants in the manure amendments were dark green in color, and of larger

* *Hawaiian Planters' Record*, Vol. XXXIII, No. 2, April, 1929, p. 155.

size, except for those in the 75 per cent amendments, which were about the size of the controls. In those soils with larger manure amendments leaf burn and firing of the lower leaves were prevalent.

Root Observations at Three Months. Pot No. 1 Control: The root mass appeared normal for the size of the plant and was characterized by a good development of secondary and tertiary roots and small rootlets. The roots were in general of the fine and wiry type with no large or stimulated roots, such as are common in rich soils.

No. 5. Twenty-five Per Cent Manure: This plant had the largest root mass of the series, characterized by many large, white primary roots, which were mostly healthy. Compared with the control, there were few secondary and tertiary branches, and fine rootlets. A considerable number of the large white roots showed *Pythium* root rot lesions, i. e., yellow to red cankered areas and root tips, many of the latter being flaccid.

No. 9. Fifty Per Cent Manure: Nearly the same root mass was noted as in No. 5, but there was more evidence of *Pythium* injury. Forced branching of the primaries was common following *Pythium* rot of the tips of these roots.

No. 13. Seventy-five Per Cent Manure: Large white primaries were present as in Nos. 5 and 9, but not nearly as numerous. The total root mass was much reduced. Forced branching with large secondaries was common. There were very few small, fine rootlets. *Pythium* rotting of the larger roots with red discoloration was a conspicuous feature, with a flaccid condition of root tips very common on roots of all sizes.

Another series was washed a month later with improved conditions of root health being noticed. The pots were in the open and subject to leaching from rains. On May 28, all remaining units were washed.

Observations: Controls: No. 3; small top as if starving; no stooling; no root rot. No. 4; larger top, with fair green color; two new shoots starting; no root rot.

No. 8. Twenty-five Per Cent Manure: Top much larger than controls, with darker green color, and abundant stooling. Root mass large and filling the pot; no root rot.

Nos. 10 and 12. Fifty Per Cent Manure: The tops were large and green, with good stooling. Roots not quite as well developed as in No. 8 and some showed *Pythium* root rot.

Nos. 15 and 16. Seventy-five Per Cent Manure: The tops were about the same as those of Nos. 10 and 12. There was less stooling than in the 50 per cent manure. Not much of the original root system remained, but there was a predominance of new root growth with some root rot in evidence. These pots seemingly retained enough of the plant food from the manure to stimulate growth, as evidenced by the large white roots, though these latter were at this time not sufficiently hyperstimulated to be readily attacked by *Pythium*.

We infer from this experiment that root growth of H 109 may be stimulated to the point that root rot becomes serious. This requires an excessive amount of plant food. The concentration required to induce susceptibility is so high that it is not likely to occur in the field or to be maintained long if reached accidentally in

localized areas. As soon as the concentration of nutrients becomes reduced as by use of the plant for growth, and leaching, normal root growth is resumed.

Effect of Molasses, Mudpress and Bagasse on Root Rot

In "Notes on *Pythium* Root Rot, V"* the effect of molashcake on root rot of Lahaina was discussed. Since this material was so effective in causing root rot of Lahaina in "healthy" soil, experiments were conducted separately on the main ingredients of molashcake to determine which ingredients were the most active. These experiments, Nos. 113, 114, 115, are discussed below. The results are given, in elaboration of the idea that it is the stimulative nature of the amendments that leads to root growth which is susceptible to the attack of *Pythium aphanidermatum*.

Experiment 113—Effect of Molasses on Root Rot

An experiment to test the effect of amendments of molasses, and molasses with sodium nitrate on root rot of Lahaina and H 109 in pathology plot soil, was conducted in 12-inch pots. There were control pots with no molasses, pots with one, two and three pounds of molasses respectively, and a series with the named amounts of molasses plus three grams of sodium nitrate per pot. One-half of the pots were planted with Lahaina and one-half with H 109.

The pots were filled with well mixed pathology plot soil. The molasses and molasses-plus-nitrate pots received the application of the amendments January 4, 1929. All pots were kept moist until March 28, 1929, to facilitate decomposition of the molasses. Planting was done on the latter date, with healthy cuttings from Kailua. Growth was fairly uniform throughout the series with somewhat better foliage color in plants grown in the amended soils. Stooling was also more vigorous in the amended soils. Correlated with this, there appeared to have been a stimulated root growth in the amended soil with serious root rot in the Lahaina, but scarcely a trace in the H 109. The roots of all plants were washed free of soil at the conclusion of the experiment June 25, 1929.

Table II shows the number of pots, treatment of soil three months before planting, cane variety and presence or absence of root rot. Fig. 1 shows the root systems of representative Lahaina plants. The experiment confirms an earlier one in that molasses amendment again induced serious root rot in a soil normally "healthy" for Lahaina cane. Root rot also appeared to be further aggravated by the addition of sodium nitrate to the molasses amendments.

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* Op. cit.

Fig. 1. Effect of molasses and nitrate of soda amendment on Lahaina roots. No. 1, Control, Lahaina; No. 4, Control, H 109; No. 6, Lahaina, one pound molasses amendment; Nos. 9-10, two pounds; No. 13, three pounds; No. 17, three pounds molasses plus 3 grams sodium nitrate.

TABLE II

Pot No.	Variety	Treatment	Root Rot
1	Lahaina	Control	None
2	Lahaina	"	"
3	H 109	"	"
4	H 109	"	"
5	Lahaina	1 lb. Molasses	Serious
6	Lahaina	"	"
7	H 109	"	Trace
8	H 109	"	None
9	Lahaina	2 lbs. Molasses	Serious
10	Lahaina	"	"
11	H 109	"	None
12	H 109	"	"
13	Lahaina	3 lbs. Molasses	Serious
14	Lahaina	"	"
15	H 109	"	None
16	H 109	"	"
17	Lahaina	1 lb. Molasses, 3 gm. $NaNO_3$	Extreme
18	Lahaina	" "	"
19	H 109	" "	None
20	H 109	" "	"
21	Lahaina	2 lbs. Molasses, 3 gm. $NaNO_3$	(No Germination)
22	Lahaina	" "	Extreme
23	H 109	" "	None
24	H 109	" "	"
25	Lahaina	3 lbs. Molasses, 3 gm. $NaNO_3$	Extreme
26	Lahaina	" "	"
27	H 109	" "	None
28	H 109	" "	"

Experiment 114—Effect of Bagasse on Root Rot

An experiment with pathology plot soil with bagasse, and with bagasse and nitrate of soda amendments was conducted in 12-inch pots. This experiment was designed to reveal the effect of relatively inert organic matter on Lahaina roots. Well mixed pathology plot soil was used. Control soil and amended soil units were prepared as shown in Table III, January 9, 1929. These were kept moist until March 30 or about three months, to allow decomposition, at which time all were planted with healthy Lahaina cuttings from Kailua.

Growth as estimated by size of tops and color of foliage was somewhat depressed in all the amended soils. Stooling was rather poor also in comparison with the controls. The roots were washed free of soil June 25, 1929.

There was no stimulation of root growth such as was found conspicuous in amendments of stable manure, molasses or cane compost, and no root rot. All roots remained of small size, thread-like or fibrous. The controls in pathology plot soil showed a few large roots with some insignificant *Pythium* root rot.

It was noted that the bagasse had not decomposed to any great extent, even in the presence of the nitrate of soda, during the five months of the experiment. The pots were in the open and exposed to rains.

Fig. 2. Effect of bagasse and nitrate of soda amendments on Lahaina roots. No. 11 Control. No. 1, one pound bagasse; No. 5 same as No. 1 plus 3 grams nitrate; No. 7 same as No. 1 plus 5 grams nitrate; No. 10 same as No. 1 plus 10 grams nitrate.

There was no apparent stimulating effect by the amendments, and there was no root rot induced by the bagasse as used. The results were interesting, conversely, since we are assuming as a working hypothesis that it is the hyperstimulated root system which is subject to *Pythium* attack. It also appeared that the bagasse controlled any tendency of the roots to be stimulated by the nitrate. Table III shows the details of the experiment and Fig. 2 shows the root systems of representative units. The better plants and roots were noticed in the controls. The bagasse-plus-nitrogen series was next in order. The plants and roots in soil amended with bagasse alone were noticeably the poorest of all.

TABLE III

Pot No.	Treatment	Root Rot
1	Bagasse 1 lb.	None
2	"	"
3	"	"
4	"	"
5	Bagasse 1 lb., 3 gm. $NaNO_3$	"
6	" "	"
7	Bagasse 1 lb., 5 gm. $NaNO_3$	"
8	" "	"
9	Bagasse 1 lb., 10 gm. $NaNO_3$	"
10	" "	"
11	Control	"
12	"	Trace
13	"	None
14	"	Trace

EXPERIMENT 115—EFFECT OF PRESS CAKE ON ROOT ROT

At the same time that the above experiments with molasses and bagasse were started, a simlair experiment was prepared with pathology plot soil and press cake amendments, with and without sodium nitrate. After an incubation period of about three months, the pots were planted with Lahaina cuttings from Kailua, on March 28, 1929.

Table IV shows number of pots, treatment and effect on root *health.* With 1 pound of press cake alone growth of roots as well as tops was moderately stimulated. There was only moderate root rot. With the same amount of press cake plus 3 grams of sodium nitrate, root growth was noticeably more stimulated as indicated by the larger size of roots. There was a conspicuous localization of root rot in the larger roots. With 5 grams of sodium nitrate the root systems were somewhat better, possibly with less root rot at the time observed. With 10 grams of sodium nitrate the roots were very badly reduced by root rot. They had been attacked nearly as fast as they developed and rotted off before they reached a length of six inches. The top was withering, dry and pale and there was a burning and firing of the lower leaves. Throughout the experiment there was a conspicuous firing of the lower leaves with some burning of the edges and tips of young leaves, most marked in pots Nos. 7, 8, 9 and 10.

Fig. 3. Effect of press cake and nitrate of soda amendments on Lahaina roots. Nos. 1 and 4, one pound of press cake. No. 5, same plus 3 grams sodium nitrate; Nos. 7 and 8 same plus 5 grams sodium nitrate. No. 9 same plus 10 grams sodium nitrate; No. 14 control.

Top growth, stooling and root growth were all stimulated by the additions of press cake and press cake plus nitrate of soda. This was accompanied by a tendency to root rot. Fig. 3 shows the root systems of representative units.

TABLE IV

Pot No.	Treatment	Root Rot	Leaf Burn
1	1 lb. Press Cake	Trace	None
2	"	Moderate	"
3	" (No germination)	.....	.....
4	"	Moderate	None
5	1 lb. Press Cake, 3 gm. $NaNO_3$	"	"
6	" "	Conspicuous	"
7	1 lb. Press Cake, 5 gm. $NaNO_3$	Trace	"
8	" "	Moderate	Present
9	1 lb. Press Cake, 10 gm. $NaNO_3$	Serious	"
10	" "	"	"
11	Control	None	None
12	"	"	"
13	"	"	"
14	"	"	"

Effect of Compost in Sterilized Soil Mixtures

It has been reported* that cane compost in amounts of 20 to 40 per cent by volume induced root rot of Lahaina in "healthy" Makiki soil. To note if compost *per se* exerted any harmful effect, or caused root collapse, mixtures of soil and compost were steam sterilized. Root study boxes were also sterilized and the soil placed therein. The various units and controls as shown in Table V were planted March 30 with Lahaina cuttings from Kailua, which had been cleaned and soaked ten minutes in a 1-1000 solution of mercury bichloride. The cuttings were rinsed thoroughly before planting. Plants were watered throughout the experiment with tap water. As shown in Table V, a parallel series was conducted with comparable mixtures, unsterilized, the cuttings having been similarly disinfected.

TABLE V

Box No.	Soil		Root Rot
1	Makiki soil	Sterilized	None
2	" "	"	"
3	Makiki soil 60 per cent + compost 40 per cent	"	"
4	" " " "	"	"
5	Makiki soil	Unsterilized	"
6	" "	"	"
7	Makiki soil 60 per cent + compost 40 per cent	"	Moderate
8	" " " "	"	"

The roots were washed June 29, 1929. It was significant that although the roots were stimulated in the sterilized soil to better development and formation of larger sized roots than is usual for natural Makiki soil, no root collapse was

* Notes on *Pythium* Root Rot, IV, *Hawaiian Planters' Record*, Vol. XXXII, No. 4, p. 468

present in the absence of specific organisms. With compost added there was a considerably greater stimulation of root development with large roots predominating, yet no root rot occurred in this sterilized amended soil.

In the unsterilized soil without amendments no root rot occurred. The roots were mostly of the small, fibrous type associated with soils only moderately supplied with nitrogen. With compost, however, in the unsterilized soil the roots were stimulated to better development. Considerable root rot was present in these root boxes (Nos. 7 and 8).

Paralleling the last mentioned experiment with compost, a similar experiment was conducted simultaneously and in the same manner with stable manure. Table VI shows the observations made when the roots were washed after a growing period of three months.

TABLE VI

Box No.	Soil		Root Rot
1	Makiki soil	Sterilized	None
2	" "	"	"
3	Makiki soil 80 per cent, manure 20 per cent	"	"
4	" " "	"	"
5	Makiki soil	Unsterilized	"
6	" "	"	"
7	Makiki soil 80 per cent, manure 20 per cent	"	Serious
8	" " "	"	"

Root rot was found only in the unsterilized soil amended with 20 per cent manure. These units had a very poor root system. In the soil alone, the roots were noticeably darker colored in the unsterilized than in the sterilized soil, but apparently equally healthy.

Olaa Soil Studies

Soil in Field J-2 at the Olaa Sugar Co., Ltd., has proved decidedly unfavorable for Lahaina cane. Soil at Makiki still grows fair Lahaina. Raymond Conant, agriculturist, Olaa Sugar Co., Ltd., collected Olaa soil for the following experiment, which was conducted at Makiki, to note the effect on root health of Lahaina grown in various mixtures of the two soils, i. e., Olaa and Makiki.

Duplicate root study boxes were prepared of Olaa soil and of nine series of dilution, ranging from one-tenth Olaa soil mixed with nine-tenths Makiki soil, to nine-tenths Olaa soil and one-tenth Makiki soil. Table VII shows the arrangement and results observed. The units were planted March 30, 1929, with healthy Lahaina cuttings from Kailua, cleaned, soaked in 1-1000 bichloride of mercury for ten minutes and thoroughly rinsed.

TABLE VII

Box No.	Soil	Germination	Improved Root Health Over Check	Root Rot
1	Control Olaa soil	—		.....
2	" " "	+		Bad
3	" " "	+		"
4	" " "	—		.....
5A	Olaa soil 9/10, Makiki soil 1/10	+	None	Bad
5B	" " " " " "	+	"	"
6A	Olaa soil 8/10, Makiki soil 2/10	+	"	"
6B	" " " " " "	+	"	"
7A	Olaa soil 7/10, Makiki soil 3/10	+	?	"
7B	" " " " " "	+	?	"
8A	Olaa soil 6/10, Makiki soil 4/10	+	Slight	"
8B	" " " " " "	+	"	"
9A	Olaa soil 5/10, Makiki soil 5/10	+	Marked	Moderate
9B	" " " " " "	+	"	"
10A	Olaa soil 4/10, Makiki soil 6/10	+	"	"
10B	" " " " " "	+	"	"
11A	Olaa soil 3/10, Makiki soil 7/10	+	"	"
11B	" " " " " "	+	"	"
12A	Olaa soil 2/10, Makiki soil 8/10	+	Very marked	Trace
12B	" " " " " "	+	" "	"
13A	Olaa soil 1/10, Makiki soil 9/10	+	" "	"
13B	" " " " " "	+	" "	None
14A	Makiki soil	+	Normal	"
14B	" "	+	"	"

The root systems of this series of plants were washed after a growing period of three months. In the "sick" Olaa soil and in the mixtures wherein this soil predominated over the "healthy" Makiki soil root rot was prevalent. However, there was a rapid decrease of root rot in the series up to the half-and-half mixture, with a more gradual decline as the proportion of healthy soil was further increased. The contrast in root health was particularly marked when the root systems grown in soil mixtures containing more than one-half Olaa soil were compared with those grown in mixtures containing less than one-half Olaa soil. Figs. 4 and 5 illustrate this comparison, the root systems of typical representatives of the series of plants being shown. The relative length and density of roots are shown, though the degree of health or rotting is not discernible in such photographs. Root rot was inconsequential where Olaa soil was present in amounts of 20 to 30 per cent by volume.

Fig. 4. Effect on Lahaina roots of dilution of Olaa "sick" soil with Makiki "healthy" soil. No. 2, Olaa soil; No. 5, Olaa soil 9/10, Makiki 1/10 by volume; No. 6, Olaa soil 8/10, Makiki soil 2/10; No. 7, Olaa soil 7/10, Makiki soil 3/10; No. 8, Olaa soil 6/10, Makiki soil 4/10.

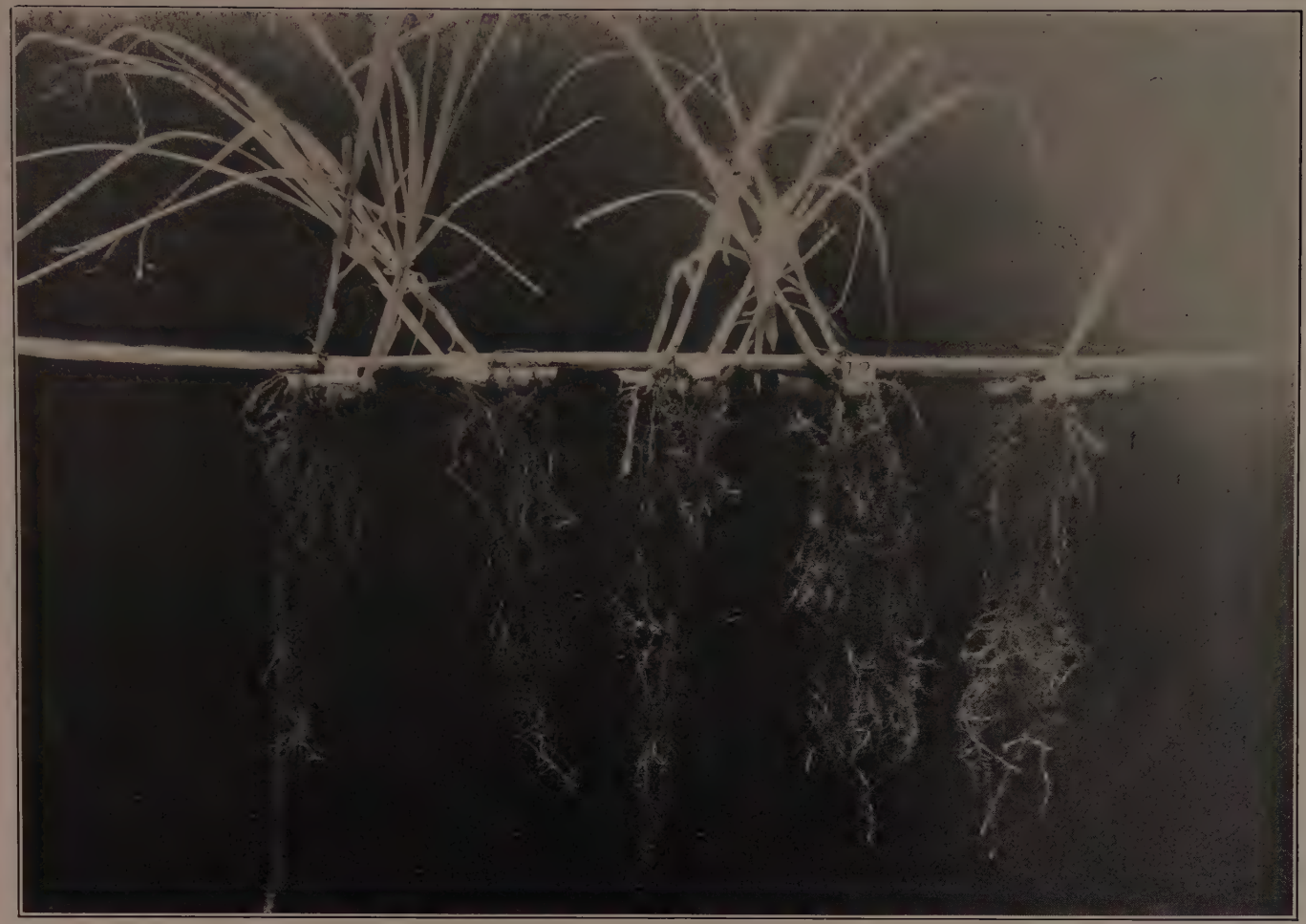

Fig. 5. (Fig. 4 cont.). No. 9, Olaa soil 5/10, Makiki soil 5/10; No. 10, Olaa soil 4/10, Makiki soil 6/10; No. 11, Olaa soil 3/10, Makiki soil 7/10; No. 12, Olaa soil 2/10, Makiki soil 8/10; No. 13, Olaa soil 1/10, Makiki soil 9/10.

Discussion

In an earlier experiment* it was found that when molashcake was allowed to decompose in healthy soil, the latter became a "sick" soil for Lahaina cane; root rot was greatly aggravated in Waipio sick soil by smaller amendments of molashcake. It was found in the present studies that molasses and press cake, the chief nutrients in molashcake, stimulated growth and were active in producing root rot conditions of a healthy soil, while bagasse was not. The latter depressed growth, counteracted any stimulating tendency of the sodium nitrate present, and no root rot occurred. Bagasse might have a useful role as a soil amendment in suitable combinations with molasses to retard disintegration, extend beneficial effects and check any harmful tendencies. That this material can be used as a dry carrier for molasses has been demonstrated by J. A. Verret† and F. E. Hance. Suitable formulae from the viewpoint of desirable biological effects in various soils might be quite different from a mechanical mixture most convenient for field application.

Experiments above cited showed that cane compost or stable manure amendments did not *per se* cause root collapse (Tables V and VI). These materials served as stimulative plant foods, the roots in such steam sterilized amended soil being large and healthy. No root rot occurred, nor any semblance of root collapse. In such amended soils not steamed, *Pythium* root rot was severe. Steam sterilization of a healthy soil has been observed to bring about conditions favorable for root rot, and this disease occurred as soon as *Pythium* was present.

In another experiment, above cited, a "sick" soil was diluted progressively with "healthy" soil, and the effect on the roots of Lahaina observed. As the proportion of "sick' soil decreased root rot became less severe. Improvement in root health was marked when the sick soil was about one-half of the mixture. Root rot all but disappeared in mixtures where the sick soil was but 20 per cent of the whole.

As already reported root rot has been induced in healthy soils by amendments of cane compost, stable manure, molashcake, mud press, molasses and sodium nitrate. These materials, whatever their other characteristics, act as stimulative plant foods. With bagasse amendments, as used, any stimulative tendency of the nitrate of soda present was overbalanced, growth was depressed and no root rot occurred. Traces of root rot did occur in some of the "healthy" soil controls. The Makiki soil is so nearly free of *Pythium* root rot of Lahaina as compared to field soils where this cane suffers severely that it is called "healthy" in these notes.

Accumulated experimental evidence thus shows that a "healthy" soil can be made "sick" for Lahaina cane by stimulative amendments, or by other means of increasing available nutrients, as by steam sterilization and subsequent invasion by *Pythium* species. The harmful accessory factor of *Pythium* in a "sick" field soil can be rendered impotent by dilution of the soil with healthy soil. In view of these

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* Notes on *Pythium* Root Rot, V, *Hawaiian Planters' Record*, Vol. XXXIII, No. 2, p. 164.

† Report by J. A. Verret, in Director's Monthly Report, September, 1927; also Proceedings, H. S. P. A., 1927, pp. 89-90.

premises it seems obvious that *Pythium* root rot varies in severity with the concentration of stimulative nutrients.

The theory was advanced* that susceptibility to *Pythium aphanidermatum* was acquired by the roots, and that it was a temporary condition of the root system varying with soil environment. The controlling factor in this acquired susceptibility now appears to be rate and type of growth as determined by stimulative nutrients. The alternate theory, that increased root rot might be due to the stimulative effect of these environments on the fungus, remains to be considered. Experiments may be conducted to learn whether the parasitic tendencies of *Pythium* can be increased by culturing the organism on various stimulative media. Since parasitic ability of the *Pythium* cultures has not been a difficulty encountered in experiments over several years, the impression has been gained that root modification was a more logical inference, than variability in the habit of the fungus. It does not appear logical that *Pythium per se* requires 5 per cent of stable manure in a soil to enable it to attack Lahaina, and around 50 per cent of the same amendment to enable it to attack H 109 seriously. The literature supports the view that a too stimulative environment for plants leads to the development of tissues more susceptible to fungus attack.

From a practical viewpoint, if *Pythium* becomes a harmful factor in cane culture only in over stimulative soils, it does not appear very important to know whether the cane, the fungus or both are modified in behavior by the environment.

Summary

1. Serious root rot of H 109 caused by *Pythium aphanidermatum* was induced in a potted soil by amendments of stable manure, 25 per cent to 50 per cent by volume. It is inferred that the observed later resumption of healthy root growth was the result of a reduced concentration of the stimulative nutrients by assimilation and leaching.

2. Root rot of Lahaina was induced in a "healthy" soil by amendments with molasses and mud press respectively. Bagasse, another constituent of molashcake, depressed growth, and no root rot occurred. The previously reported adverse effect of molashcake on root rot was apparently due to the stimulative ingredients, molasses and mud press, and not to the bagasse.

3. No root collapse of Lahaina was found in soil amended with manure or compost and steam sterilized. In such amended soils, not sterilized, *Pythium* root rot was active. Heavy amendment with these materials did not *per se* cause root collapse.

4. When a "sick" soil was diluted progressively with a healthy soil, *Pythium* root rot became less severe. With a half-and-half mixture, a marked improvement of root health was observed. In mixtures containing less than 20 to 30 per cent sick soil, *Pythium* root rot became inconsequential.

* Notes on *Pythium* Root Rot, III, *Hawaiian Planters' Record*, Vol. XXXII, No. 3. pp. 279-288.

5. It is inferred from these experiments that the accessory controlling factor in *Pythium* root rot of Lahaina cane is the type of root growth as determined by stimulative nutrients. Temporarily acquired susceptibility appears to be a function of root nutrition when the nutrients available become too stimulative. In lesser amounts this harmful factor acts as a beneficial soil constituent.